Prescribed Fire Management in Sandplain grasslands and heathlands: Impacts of Burn Seasonality and Intensity on Vegetation Composition, Head of the Plains, Nantucket MA

By: Jennifer M. Karberg
Research Supervisor
Nantucket Conservation Foundation
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Introduction

Nantucket Island, MA hosts a large population of rare and endangered plant and animal species, primarily due to a prevalence of large areas of early successional plant communities. In particular, sandplain grassland and heathland vegetation communities represent the dominant early successional communities on Nantucket and are classified as globally rare habitats by NatureServe [NSE 2009]. These habitats originally dominated coastal areas on sandy well-drained soils throughout northeastern North America (Sorrie and Dunwiddie, 1996; Swain and Kearsley, 2001) but have declined by ~ > 90% since the mid-1800s due to anthropogenic development and a lack of disturbance leading to increased woody species establishment (Godfrey and Alpert, 1985; Barbour *et al.,* 1998). Sandplain grasslands and heathlands are globally significant habitats containing ericaceous shrubs such as bearberry (*Arctostaphylos uva-ursi*), black huckleberry (*Gaylussacia baccata*), and lowbush blueberry (*Vaccinium angustifolium*), as well as graminoids including little bluestem (*Schizachyrium scoparium*) and Pennsylvania sedge (*Carex pensylvanica*), and a large component of forbs such as bushy aster (*Symphyotrichum dumosum*), sickle-leaved golden aster (*Pityopsis falcata*), and gray goldenrod (*Solidago nemoralis*). Sandplain grasslands tend to have a higher dominance of graminoid and herbaceous species while heathlands contained more low shrubs and woody species. In addition to these more common species, Nantucket's Sandplain grasslands and heathlands support one of the highest concentrations of rare and endangered species in the Commonwealth (Barbour *et al.*, 1998; Beers & Davison, 1999; Carlson *et al.*, 1991; Steel, 1999) and are of significant conservation concern, as they are at risk of extirpation from both development and vegetative succession (Barbour *et al.*, 1998).

The current dominance of rare sandplain grassland and heathland habitats on Nantucket was driven by the island's unique human history (Tiffney and Eveleigh, 1985; Sorrie and Dunwiddie, 1996; Swain and Kearsley, 2001). Since the retreat of the last glacial advance in the early Holocene, harsh coastal environments and a continuous Native American presence maintained open, early successional habitats (Dunwiddie, 1990; Motzkin and Foster, 2002). European colonization of the island brought intensive sheep grazing, agricultural prescribed fire, and firewood and timber cutting, which expanded and maintained large areas of sandplain grassland vegetation. As the island became more extensively developed, grazing and burning activities decreased between 1980 and 1920 (Tiffney and Eveleigh, 1985), with the lack of disturbance pressure leading to an increase in woody species dominance and a loss of these rare early successional habitats in many areas.

Both the historic and ecological significance of these globally rare plant communities make the successful development of management techniques aimed at preventing succession to habitats

dominated by woody species, particularly scrub oak (*Quercus ilicifolia* and *Q. prinoides*) and pitch pine (*Pinus rigida*), an important and urgent conservation priority on Nantucket.
Prescribed fire can provide a valuable management tool particularly since historic fire regimes likely played a role in the maintenance of sandplain grassland and heathland communities on Nantucket (Dunwiddie, 1994).

Prescribed fire management can alter ecosystem characteristics in many ways that may encourage the persistence of grassland habitat. Fire has been shown to increase productivity in grasslands by improving microsite characteristics. Fire typically consumes only portions of the surface vegetation and litter layers (Baker, 1990; Richter *et al.*, 1982), creating a mosaic of treated and untreated vegetation. This mosaic effect increases biodiversity and provides refugia for insects and wildlife that can re-colonize the site following the fire (Barbour *et al.*, 1998; Raleight *et al.*, 2003). The removal of litter by fire can create a spike in nitrogen and phosphorous in the soil through nutrient release (Briggs & Knapp, 1995; Dhillion & Anderson, 1993; Hurlbert, 1988) and may expose the soil to increased solar radiation, resulting in higher soil temperatures. Benefits of higher soil temperatures include increased number and activity of nitrifying bacteria (Daubenmire, 1968; Old, 1969) and increased allocation of resources to plant growth (Ojima *et al.*, 1994). The patchy areas of bare ground created by litter removal can open up space for seed germination and encourage the proliferation of early successional species, particularly those that are fire adapted.

The effectiveness of prescribed fire as a tool for maintaining sandplain grasslands and coastal heathlands by reducing the encroachment of woody species and perpetuating important plant species has not been definitively documented (Dunwiddie, 1998; Niering & Dreyer, 1989; Vickery, 2002). Efforts to restore or create sandplain grassland and coastal heathland communities from current shrub dominated areas have seen limited success, placing high conservation priority on preventing existing grasslands and heathlands from succeeding to woody-dominated habitats. This research project was designed and initiated to examine the effectiveness of dormant season (spring and fall) and growing season (late summer) prescribed fire as a tool for maintaining existing grassland and heathland communities and reducing the cover of woody species in coastal heathland habitat adjacent to existing grasslands.

Objectives

The goals of this research are to:

1) Document the effectiveness of prescribed fire as a means of maintaining and increasing sandplain grassland and coastal heathland habitat composition.
2) Compare the effectiveness of spring dormant season, fall dormant season, and growing season (late summer) prescribed fire in reducing the abundance of woody species in areas of coastal heathland habitat.

Methods

Site Description and Existing Vegetation Communities

This project was conducted on the Nantucket Conservation Foundation's Head of the Plains property (436 acres) located on the southwest shore of Nantucket Island, MA (Figure 1). Head of the Plains is bordered by 92 acres owned by the Federal Aviation Administration to the northwest, 578 acres protected by the Nantucket Islands Land Bank Commission to the north, and an additional 780 acres of NCF-owned land at Sanford Farm, Ram Pasture, and The Woods to the northeast. All of these properties fall within the Massachusetts BioMap "Core Habitat," meaning that they represent the highest priority for biodiversity conservation and protection within Massachusetts (Natural Heritage, 2001).

Head of the Plains contains the largest, contiguous acreage of sandplain grassland and heathland habitats currently under NCF ownership. Prior to the initiation of this project, no comprehensive plant surveys had been conducted on this property; however at least two state-listed plant species had been observed anecdotally, including sandplain blue-eyed grass (*Sisyrinchium fuscatum*) and New England blazing star (*Liatris scariosa* var. *novae-angliae*). In addition, over 15 state-listed plant species were known to occur in similar habitats on Nantucket, including sandplain flax (*Linum intercursum*), eastern silvery aster (*Symphyotrichum concolor*), and lion's foot (*Nabalus serpentarius*). Furthermore, the short-eared owl (*Asio flammeus*) and northern harrier (*Circus cyanneus*), two state-listed birds of prey, had been documented as nesting on the property. There were also several species of rare Lepidoptera that occur on Nantucket and are associated with coastal heathland and sandplain grassland habitats, including the chain-dotted geometer (*Cingilia catenaria*), Melsheimer's sack-bearer (*Cicinnus melsheimeri*), barrens daggermoth (*Acronicta albarufa*), and coastal heathlands sallow (*Chaetaglaea cerata*) (Mellow, 2004).

Although approximately 80 acres in this area were treated with prescribed burning prior to the implementation of this project, the rest of this site had not been managed and, to our knowledge, there had been no prior ecological monitoring conducted.

Vegetation communities at the site were categorized using a GIS map produced by The Nature Conservancy (TNC) that distinguishes 36 distinct communities on Nantucket based on 1:12,000 color and infrared stereo aerial photography taken in 1993 (Figure 2). The relative abundance of the vegetation communities present in the area shown in Figure 2 are as follows:

Vegetation Community Type	**Acreage**	**Percentage**
Sandplain Heathland	254.0	58.2
Open Scrub Oak	59.8	13.7
Closed Scrub Oak	36.1	8.3
Sandplain Grassland	26.9	6.2
Pitch Pine-Mixed Scrub Oak Woodland	16.8	3.8
Coastal Shrubland	13.0	3.0
Coastal Dune Community	8.5	1.9
Sand	7.7	1.8
Coastal Salt Pond	3.3	0.8
Pitch Pine-Scrub Oak Woodland	2.7	0.6
Typha Marsh	2.2	0.5
Mowed Grassland	1.8	0.4
Marsh	1.6	0.4
Black Pine Woodland	1.4	0.3
Developed Land	0.4	0.1
TOTAL	**436.2**	**100.0**

Vegetation Community Sampling

In 2004 and 2005, thirteen management units (~15 acres in size) were established at the Foundation's Head of the Plain's property, with nine designated burn units for inclusion in this study (Figure 3). In each unit, 30 random independent points, located a minimum of 10m apart, were selected using ArcGIS (Figure 3). These points were located in the field and $1m^2$ vegetation community sampling plots were established and permanently marked at each point (n=30). Vegetation sampling of every plot within each of the nine burn units was performed at least 1 year prior to treatment by prescribed fire and then resampled up to 5 continuous years post-burn.

In each $1m^2$ plot, we identified herbaceous and woody plants to the species level (whenever possible) and estimated percent cover in categories as follows: 0%, 1-2%, 2-5%, 5-10%, 10-25%, 25-50%, 50-75%, and 75-100%. Additionally, percent cover of the following groups was determined in each 1 m^2 plot: total vegetative cover[1], canopy[2], dead woody[3], grasses[4], forbs[5], cryptograms[6], bare ground[7], litter[8], ash[9], and duff[10]. Woody cover was assessed as both total woody cover and in 5 separate 0.5 m height classes (Woody 1 less than or equal to 0.5m; Woody 2 less than or equal to 1m…etc…Woody 5 greater than 2 m). Ground cover estimates (i.e. bare ground, litter, duff, and ash) were required to total 100%.

> [1]**Total vegetative cover:** All live plant material within the plot.
> [2]**Canopy:** Plants that are rooted outside of the plot and hanging into the plot or growing through the plot.
> [3]**Dead woody:** Plants that are rooted in the ground and are completely devoid of live vegetation.
> [4]**Graminoids:** All grasses, sedges, and rushes. Grass that was rooted in the plot but brown was included in the estimate.
> [5]**Forbs:** Herbaceous plants that are not graminoids.
> [6]**Cryptogams:** Any flowerless, seedless plant that reproduces by spores, as fungi, algae, ferns, and mosses.
> [7]**Bareground:** Mineral soil.
> [8]**Litter:** Detached plant material.
> [9]**Ash:** Grey, burned plant material.
> [10]**Duff:** The layer of decomposing organic materials that resides between the mineral soil and the litter layer. This organic matter is in various stages of decomposition and is often compacted.

Prescribed Fire Effects Monitoring

During and after prescribed burns in each burn unit, we measured flame temperature and duration, fuel moisture, and burn severity. In order to obtain a quantifiable estimate of overall seasonal precipitation patterns, we also estimated the Keetch-Byram Drought Index, or KBDI (Keetch & Byram 1968) for each day a prescribed burn was conducted.

Flame Temperature and Duration

Flame temperature and duration were measured using thermocouples paired with HOBO U12 data loggers buried outside of but adjacent to each of the 30 $1m^2$ vegetation sampling plots. Thermocouples have been shown to be the most direct method for acquiring temperature and residence time during prescribed burns (Wally et al. 2006). Data loggers were sealed inside static proof bags and placed in sealed Rubbermaid containers to prevent moisture from damaging the loggers. Data loggers were connected by a buried wire to the thermocouple probe, which was placed along the southern boundary of the $1m^2$ plot so as not to disturb the vegetation within the plot. The thermocouple setup was buried in a hole approximately 20cm deep. Extreme care was taken to avoid disturbing the vegetation around the plot, which could reduce or otherwise influence fire behavior. Data loggers were connected to the thermocouple probes and launched on the morning of the burn to record continuous data for up to 10 hours. The logger and thermocouple setup was collected immediately after the prescribed burn was finished and it was safe to access the burn unit. The data was downloaded from the data loggers immediately (less than 24 hours) after the fire.

Data loggers were programmed to record temperature once per second over the course of the prescribed fire. Files downloaded from each thermocouple included a suite of information related to temperature recorded over the course of the prescribed fire. The two primary measures analyzed in this study as indicators of fire intensity were Mean60 and Mean150 (Wally et al 2006), both measures of temperature related to residence time. Mean60 represents the number of minutes during the burn where the average recorded temperature was > 60°C. 60°C represents the temperature at which plant cell death occurs (Levitt 1980) and is often used as an indication that a burn actually occurred. Mean150 represents the number of minutes during the burn where the average recorded temperature was >150°C, representing a slightly higher intensity in fire impacts on vegetation.

Fuel Moisture

At least 48 hours prior to the burn, fuel moisture sticks were set up at three randomly chosen locations within the burn unit. The three locations were selected to represent different fuel types found within the unit and locations were precisely documented using a handheld GPS unit. Fuel moisture sticks were weighed and collected immediately prior to the prescribed burn in order to estimate the 10-hour fuel moisture content of the surrounding vegetation.

To examine the percent live fuel moisture in the burn unit, live fuel moisture samples were collected on the day of the burn. Two samples containing 40 - 80 grams of either graminoid or woody plant material was harvested from the vicinity of each of the three established 10-hour fuel moisture stick locations for a total of 3 graminoid samples and 3 woody samples per burn unit. Plant material was immediately placed in large glass canning jars sealed tight to prevent moisture loss. Samples jars were weighed and placed in a drying oven (at ~ 60°C) at the University of Massachusetts Boston Nantucket Field Station. Samples were reweighed every 1-2 days until the weights stabilized. The final weight of dried samples was estimated as the difference between the initial weight and the final weight of each jar (minus the weight of the empty jar). Live fuel moisture was calculated as the percent difference between the initial and final weights of each dried sample.

Burn Severity

Burn severity was visually evaluated immediately post-burn in all 30 1m^2 vegetation plots. Percent cover was estimated in each of the following categories, which were required to total 100%:

Unburned: vegetation and groundcover not affected by fire;

Scorched: foliage yellow, litter and surface vegetation barely burned or singed;

Low severity: small diameter woody debris somewhat consumed, structure of upright vegetation apparent but foliage may be consumed, litter and duff surface may be charred but remain visible, original forms of surface materials, such as leaf litter, needle litter or lichens visible;

Moderate severity: foliage and twigs consumed, structure of the upright vegetation no longer apparent, large diameter woody vegetation partially consumed but may still exhibit structural components, litter layer may be somewhat consumed but still visible;

High severity: deep ash layer present, all or almost all of the aboveground vegetation consumed, large diameter fuels or duff layers may be consumed, rhizomes exposed, mineral soil exposed (Table 2).

Keetch-Byram Drought Index

The Keetch-Byram Drought Index (KBDI) was designed to assess fire potential based on the net effect of evapotranspiration and precipitation producing moisture deficiency in deep duff and upper soil layers (Keetch-Byram 1968). This continuous index directly relates to the flammability of organic material in the soil.

KBDI is calculated on a daily basis using weather station latitude, mean annual precipitation, maximum dry bulb temperature and the last 24 hours of rainfall.

- **KBDI = 0 - 200:** Soil moisture and large class fuel moistures are high and do not contribute much to fire intensity. Typical of spring dormant season following winter precipitation.
- **KBDI = 200 - 400:** Typical of late spring, early growing season. Lower litter and duff layers are drying and beginning to contribute to fire intensity.
- **KBDI = 400 - 600:** Typical of late summer, early fall. Lower litter and duff layers actively contribute to fire intensity and will burn actively.
- **KBDI = 600 - 800:** Often associated with more severe drought and increased wildfire occurrence. Intense, deep burning fires with significant downwind spotting can be expected. Live fuels can also be expected to burn actively at these levels.

Data Analysis

The research and management goals for this project were to burn individual management units during either the growing season prior to September 30th (Summer Burn), the fall dormant season after October 15th, provided there has been a hard frost (Fall Burn), or the spring dormant season prior to March 15th (Spring Burn). Vegetation sampling of the plots within each unit was scheduled to include at least 1 season of pre-treatment sampling and 2-5 seasons of post-treatment sampling (Table 1).

Burn conditions varied extensively over the course of this study. Individual units were only treated with prescribed fire once, but the treatment period took place over multiple years under very different climactic and environmental conditions. Therefore, year-to-year variation in burn conditions and site characteristics do not allow for direct management unit and seasonal comparisons over time. Only units with at least one year pre-sampling and 5 years post sampling were utilized for analysis in this study (Units 2, 5, 6, 8, and 9).

Changes in Vegetation Composition over Time

We examined changes in vegetation composition over time in each plot using a non-metric multidimensional scaling (NMDS) ordination with a Sorenson similarity index (PC-Ord). The ordination matrix consisted of each treated Unit (2, 5, 6, 8, 9 with n=30 plots per unit) and examined the relative percent cover of 8 functional group categories, as defined previously in the *Vegetation Community Sampling* section: Total cover, canopy, woody, woody1, woody2, dead woody, grass and forb; as well as three created categories (Grassland, Heathland, Shrubland) representing the relative percent cover of plant species associated primarily with sandplain grasslands, sandplain heathlands and shrublands. Habitat associated species were determined from the Massachusetts Natural Heritage & Endangered Species Program Natural Communities Fact Sheets [MA NHESP 2007]. There can be significant overlap between sandplain grassland, heathland and coastal scrub oak communities so some species were included in multiple categories as detailed below.

Grassland	**Heathland**	**Shrubland**
Goat's rue (*Tephrosia virginiana*)	black huckleberry (*Gaylussacia baccata*)	scrub oak (*Quercus ilicifolia*)
yellow wild indigo (*Baptisia tinctoria*)	bearberry (*Arctostaphylos uva-ursi*)	dwarf chinquapin oak (*Quercus prinoides*)
gray goldenrod (*Solidago nemoralis*	lowbush blueberry (*Vaccinium angulstifolium*)	dwarf chinquapin oak (*Quercus prinoides*)
Various aster species (i.e. toothed white topped aster (*Seriocarpus asteroids)* and bushy aster (*Symphyotrichum dumosum*)	golden heather (*Hudsonia ericoides*)	bearberry (*Arctostaphylos uva-ursi*)
yellow thistle (*Cirsium horridulum*)	chokeberry (*Aronia arbutifolia*)	
little bluestem (*Schizachyrium scoparium*)	sweetfern (*Comptonia peregrine*)	
hairgrass (*Deschampsia flexuosa*)	bayberry (*Morella pensylvanica*)	
Pennsylvania sedge (*Carex pensylvanica*)	dewberry (*Rubus* ssp.)	
poverty grass (*Danthonia spicata*)	little bluestem (*Schizachyrium scoparium*)	
bearberry (*Arctostaphylos uva-ursi*)	hairgrass (*Deschampsia flexuosa*)	
	scrub oak (*Quercus ilicifolia*)	

To determine which environmental factors might drive observed vegetation composition change over time in each management Unit, we examined Pearson and Kendall correlations of the ordination axes with a suite of environmental factors either directly measured or interpolated from collected information:

GRTemp: Average growing season temperature in each sample year;
GRPrecip: Average growing season precipitation in each sample year;
AvTemp: Average yearly temperature in each sample year;
AVPrecip: Average yearly precipitation in each sample year;
BurnIndex: Burn index;
BurnRank: Burn rank;
KBDI: KBDI at burn;
Distance: Distance from the center of each Unit to the ocean.

Burn rank and burn index were calculated to quantify the burn severity observations made immediately post-burn. Burn rank is simply the rank of the dominant burn severity category observed in each individual plot where unburned = 1, scorched = 2, low severity = 3, moderate severity = 4 and high severity = 5. Burn Index created a weighted number to sum the severity classes over the individual plot using the burn rank multiplied by the % cover midpoint of that rank and summed. For example, a plot with 87.5% moderate severity (4) would have a Burn Index of 87.5 * 4 = 350. A plot with 87.5% low severity (3) and 0.5% scorched (2) would have a Burn Index of 87.5*3 + 0.5*2 = 263.5.

Species Richness over Time
We constructed species-based rarefication curves based on species accumulation (SAC) in order to examine changes in biodiversity (represented by species richness) related to prescribed fire treatments over time within each management Unit using R version 3.0.2 (R Core Team 2013). Species rarefaction curves plot the randomized species richness against sampling intensity and can be compared to examine different species richness observed within different sampling years. The 'random' SAC method calculated the mean SAC and standard deviation using random data permutations (Gotelli & Colwell 2001).

Indicator Species Trends over Time
We examined change over time in the cover of specific indicator species within each management unit using the repeated measures general linear model in SPSS version 21.0 (IBM Corp 2012). We assessed sphericity with Mauchly's test and depending on the value of ϵ, corrected when necessary with either the Greenhouse-Geisser ($\epsilon < 0.75$) or the Huynh-Feldt ($\epsilon > 0.75$) corrections. We examined trends for little bluestem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*), black huckleberry (*Gaylussacia baccata*), lowbush blueberry (*Vaccinium angustifolium*), bearberry (*Arctostaphylos uva-ursi*), bayberry (*Morella pensylvanica*), and scrub oak (*Quercus prinoides* and *Quercus ilicifolia* combined).

Results

Ordination of Plant Composition Change
A significant three-dimensional ordination was obtained with a final stress of 4.715, which explained 85.5% of the observed variation between the different management Units over time (Figure 4). An examination of the Pearson and Kendall correlation between functional group and ordination axis showed Axis 1 positively correlated with the presence of Sandplain Heathland community specific plants ($r^2 = 0.890$), Axis 2 positively correlated with the presence of graminoid species and Sandplain Grassland community specific plants ($r^2 = 0.540$ and 0.512 respectively) and Axis 3 positively correlated with woody shrubs in the second height category (0.5-1m) ($r^2 = 0.497$) (Table 3).

Solid lines connecting each sampling event represent the relative changes in functional group composition between sampling years (Figure 4). Initial functional group composition was different for each sampled Unit, with large changes observed immediately post burn in all Units. All Units except Unit 2 appeared to be on a trajectory to return towards pre-burn functional group composition but that level had not yet been reached for any of the Units at 5 years post-burn treatment.

As each Unit was not similar in functional group composition at the beginning of the study, we can only really examine the trajectory of change within each Unit, regardless of the timing and year of treatment (Figure 4).

Unit 2 experienced a dramatic reduction in Heathland associated species in the first year post burn, with very little recovery of those species 5 years post-burn. Unit 2 also saw very little change in Grassland species composition with time.

Unit 5 had the highest initial, pre-burn composition of Heathland species, and showed a reduction in those heathland species with a corresponding increase in Grassland species after burning. By 5 years post-burn, Unit 5 showed a trend towards returning to a higher dominance of Heathland species but had still not reached pre-treatment levels.

Unit 6 and Unit 8 showed similar trajectories to Unit 5 with initial higher levels of Heathland species pre-burn and a dramatic decrease in heathland species with a corresponding increase in Grassland species after burn. Each unit appeared to be on a potential trajectory to return towards increased Heathland species but was still far from that composition 5 years post burn.

Unit 9 initially had a much lower pre-burn concentration of Grassland vegetation with a dramatic increase in grassland associated species 4 years post-burn and a subsequent reduction 5 years post burn.

Relationship between vegetation compositional change and measured environmental variables
One environmental measurement was strongly correlated to the vegetation functional group NMDS and three were more weakly correlated (Table 4). Average growing season precipitation was positively correlated to Axis 2 ($r^2 = 0.603$) and the presence of Sandplain Grassland community specific plants. Burn Index, Burn Rank and Distance to Ocean were positively correlated with Axis 1 ($r^2 = 0.350$, 0.384, and 0.310 respectively) and the presence of Sandplain Heathland community specific plants.

Species Richness in each Unit over Time
Each unit showed distinct trends in species richness overtime in response to environment and prescribed fire treatments (Figures 5-9).

In **Unit 2**, the first sampling year post-burn showed a slight decrease in species richness (Figure 5). All following sampling years showed increased species richness relative to pre-burn, with significant increases in species richness in 2009 (4 years post-burn).

Unit 5 showed very little difference in species richness between pre-burn sampling and the first year post-burn (Figure 6). All subsequent years showed a large increase in species richness, with the largest increase seen in 2009 (3 years post-burn).

Unit 6 showed a slightly different pattern of species richness, with the first year post-burn being significantly increased compared to pre-burn species richness (Figure 7). All years post-burn showed increased species richness with 2009 (3 years post-burn) again showing the greatest species richness of all sampling years.

Unit 8 was the hottest, driest burn and showed a dramatic decrease in species richness for the first year post-burn (Figure 8). Species richness quickly recovered and all subsequent years showed high species richness, with 2009 (4 years post-burn) again showing the greatest species richness. Unit 8 also shows the highest species richness over time of all of the sampled Units.

Unit 9 showed very little difference in species richness over time, with the first 2 years post-burn showing very similar species richness compared to the pre-burn (Figure 9). The greatest species richness in this Unit was not observed during 2009 as in the other Units. The line trajectory suggests that further sampling after 2011 would provide a higher species richness. The prescribed fire in Unit 9 had the lowest intensity of all sampled burns with the shortest times spent at high temperatures during the burn. This burn, which was a fall burn, may not have been intense enough to direct strong changes in species composition.

The fact that 2009 showed the highest species richness of most sampled Units regardless of fire intensity, seasonality, or years since burn indicates that environmental factors may have a stronger influence on species richness 3-4 years post burn. The highest levels of growing season precipitation occurred in 2009, with very wet and cool growing season conditions, which may have influenced species richness across all units regardless of prescribed burn treatments conducted during this study.

Indicator Species Cover Trends
Overall, individual species cover varied between units both before treatment and following treatment (Table 5; Figures 10-12). The vegetation composition of each unit was initially unique, as previously described using functional group categories and species richness accumulation trends.

Unit 9 had a relatively higher initial cover of *Gaylussacia baccata* and *Arctostaphylos uva-ursi* with low concentrations of both grass species. **Unit 2** contained the highest initial coverage of *Carex pensylvanica* compared to the other Units and moderate levels of *Quercus* spp. and *Schizachyrium scoparium*. **Unit 6** initially had a higher coverage of *G. baccata* and *S. scoparium*. **Unit 8** contained high *G. baccata*, *Morella pensylvanica* and *S. scoparium* before treatment. **Unit 5** had high initial *A. uva-ursi*, *G. baccata* and *M. pensylvanica* concentrations.

Individual species coverage varied between management Units but overall, when individual species responses to fire were detectable, they were independent of management Unit. *Vaccinium angustifolium* and *C. pensylvanica* both showed overall low percent cover in all management units before treatment and showed no appreciable response to fire application (Figure 10). *M. pensylvanica*, where present, initially had large coverage areas and experienced an initial strong decline in coverage post-burn (Figure 11). Coverage of *M. pensylvanica* did not recover to pre-treatment levels after 5 years. *S. scoparium* as well showed an overall trend of an initial decline in coverage post-fire with recovery in following years but not approaching pre-treatment coverage 5 years post-treatment (Figure 11). *Quercus* spp, *A. uva-ursi* and *G. baccata* all exhibited the response expected in fire adapted species, with an initial strong decrease in cover one year after treatment followed by a steady increase to approximate pre-treatment levels five growing seasons after burning (Figure 12).

Discussion

This study sought to examine both the influence of prescribed fire seasonality on reducing woody species coverage and to document the effectiveness of prescribed fire on maintaining and increasing sandplain grassland and coastal heathland species composition at the Head of the Plains on Nantucket, MA. Unfortunately, due to the inherent pre-burn vegetation variability in each of the management units and the environmental variability between multiple treatment years, we were not able to examine the question of seasonality influence on woody species. We were able to draw conclusions about the influence of prescribed burning on sandplain grassland and heathland vegetation communities, particularly related to the Head of the Plains property.

In general, all management units experienced a large decrease in the cover of woody species immediately post-burn and an increase in grassland specific species in the first 1 to 2 years post-burn (Figure 4). Post-burn, all management units were on a trajectory towards increasing the dominance of heathland specific species, but only Unit 9 reached pre-management levels five years post-burn (Figure 4). Historical evidence suggests that the fire frequency in most North American prairies was ~ 3-5 years (Wright and Bailey 1982). This interval might be appropriate to maintain sandplain grasslands and heathlands and create a balance of intermixed grassland and heathland associated species on the landscape.

Prescribed fire is most often applied as a management tool to drive species composition, typically to establish or maintain a particular vegetation community. Previous studies have shown that a wide range of factors can influence species compositional change on the landscape, including fire intensity and frequency, growing season temperature and precipitation, soil nutrients, etc. (Hesling and Grese, 2010). Results of this study showed that vegetation composition at the Head of the Plains was driven by three factors: initial management unit species composition, individual species responses or lack of response to prescribed fire, and growing season precipitation (both during the year of the fire and over the course of the study).

Each of the management units in this study, even though they were all located fairly close together on a contiguous piece of property, they each contained significantly different vegetation composition before treatment (Figure 4). Initial vegetation composition appeared to play a large role in vegetation composition 5 years post treatment with prescribed fire. In Units dominated by more woody species and heathland specific species, such as Unit 9, prescribed fire did not dramatically increase the composition of grassland specific species. Units with more mixed vegetation composition showed an initial decrease in woody species but quickly turned to a trajectory of increased heathland species five years post-burn. Other studies of prescribed fires in grasslands and heathlands showed mixed effectiveness at reversing a successional pathway from heathland dominated communities to grassland dominated communities using fire alone. This suggests that mixed disturbance management such as fire, grazing, harrowing, and seed addition might be more effective at significantly altering vegetation community changes over time (Motzkin and Foster, 2002; Hesling and Grese, 2010). Prescribed fire at Head of the Plains maybe important to maintain current vegetation communities as woody species coverage was just approaching pre-burn levels after a 5 year burn interval. The effects of multiple fires and fires conducted over more frequent intervals of time were not examined as part of this study and may offer and interesting method for maintaining and reversing successional trajectories.

Individual species showed dramatically different responses to prescribed fire treatment. *Schyzacharium scoparium* (little blue stem) is a dominant component of sandplain grassland communities and anecdotal observation on Nantucket indicates that burned areas show larger and healthier populations of *S. scoparium* following a fire. In this study, we saw an immediate and dramatic reduction in the coverage of *S. scoparium* following fire with some recovery 5 years post burn but not approaching pre-burn levels. Niering & Dreyer (1989) observed that *S. scoparium* increased in height, flowering and vigorousness immediately post-burn. Dunwiddie (unpublished) saw cover of *S. scoparium* decrease post burn but frequency increase. Prescribed fire appears to increase the reproductive effort of this dominant component of sandplain grassland habitat, but not necessarily promote a long term increase in population size. Repeated prescribed fire treatments might reveal whether this species will experience a negative response to fire in the long term. This is a species that might benefit more from rotating a variety of management techniques over a longer time scale.

Woody species in this study, particularly *Gaylussacia baccata* (huckleberry), *Arctostaphylous uva-ursi* (bearberry), and *Quercus* ssp (scrub oak), overall experienced an initial decrease in cover immediately following fire with a gradual return to levels equaling pre-burn coverage five years post-treatment. A fire interval on Nantucket sandplain grasslands and heathlands of 5 years may effectively control woody species at their current levels, providing a balance of sandplain grassland and heathland habitats across the landscape.

In addition to individual species responses to prescribed fire and the initial vegetation composition of each management unit, growing season precipitation strongly influenced vegetation response to fire and species richness observed in particular years. Species richness in each unit showed a dramatic jump in 2009, regardless of time since burn. Conditions during 2009 were particularly wet and cool during the growing season with higher than average precipitation, which may have influenced not only species richness overall but also the number of species that survived to the mid-summer sampling window to be included in the analysis. Additionally, analysis of environmental variables in relation to vegetation functional groups indicated a strong relationship between increased growing season precipitation and an increased dominance in grasses and grassland specific species (Table 3 and 4). Targeting prescribed fire management to coincide with potential growing season precipitation is not practical but should be considered as something that could explain particular responses in vegetation communities after management.

Conclusions

This long term examination of the influence of single year prescribed fire treatments on the vegetation composition of multiple management Units at the Head of the Plains on Nantucket corroborated previous research on sandplain grassland and heathland communities in New England and helped clarify the management time frame necessary to control the spread of woody species in this particular habitat. A five year burn interval window appears appropriate to maintain current levels of woody species. This burn interval will not decrease the cover of woody species. Further research on either more frequent prescribed fire treatments or a combination of management tools may provide a mechanism for woody species reduction. There is some evidence that a single burn may increase the reproduction of some grass species but decrease their abundance over a short time period. The influence of repeated burning on grassland species over time is unclear and should also be explored through further research.

Over the years, research examining the influence of fire on sandplain grasslands and coastal heathlands as well as other New England prairies has indicated that more than just prescribed fire may be necessary to promote these unique assemblages of plant species long term on the landscape (Motzkin and Foster, 2002; Dunwiddie, 1998, Dunwiddie, unpublished; Niering & Dreyer, 1989). Single burn treatments and spring and fall burn treatments show mixed effectiveness at preventing succession to woody dominant vegetation in the long term (Motzkin and Foster, 2002; Dunwiddie, unpublished). Prescribed burns conducted during the summer growing season may be effective (Dunwiddie & Caljouw, 1990), however, there is currently no practical means of implementing this technique at a management-level scale on Nantucket because of public safety and smoke management concerns during the height of the tourist season.

Lacking the reality and needed severity of summer burns, a combination of management tools may be the best method to restore and promote sandplain grassland and heathland communities long term on

Nantucket. Motzkin and Foster (2002) propose that the primary method for the initial creation of the large areas of these communities on Nantucket was initiated through plowing, harrowing, and grazing. Incorporating these methods in rotation with prescribed fire may help promote and expand current areas of sandplain grassland and heathland habitat. Studies of Midwestern prairie systems showed that prescribed fire alone could not maintain species diversity, and a variety of management tools such as burning, rotational grazing and seed addition may be necessary to promote diversity in important grassland systems (Hesling & Grese 2010).

The Head of the Plains is a large, contiguous property of mixed sandplain grassland and heathland communities currently experiencing some pressure to succeed to communities dominated by larger and more densely growing woody species such as scrub oak. A 5 year burn rotation should continue to maintain the current delicate balance of grassland and heathland communities although special attention should be paid to the impacts of rotational burning on grassland species, particularly little bluestem. In the future, consideration may need to be given to considering rotational grazing and native seed addition to maintain and increase populations of native grassland species that may not be encouraged by prescribed fire alone.

Works Cited

Baker, M.B.J. (1990) Hydrologic and water quality effects of fire. In Effects of fire management of southwestern natural resources (ed J.S. Krammes). USDA Forest Service, Rocky Mountain Forest and Rance Experiment Station, Fort Collins, CO.

Barbour, H., Simmons, T., & Woolsey, H. (1998) *Our irreplaceable heritage: protecting biodiversity in Massachusetts* Natural Heritage and Endangered Species Program, Boston, MA.

Beers, A. & Davison, S. (1999) *North Atlantic coast ecoregional conservation plan* The Nature Conservancy, Arlington VA.

Briggs, J.M. & Knapp, A.K. (1995) Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. *American Journal of Botany*, **82**, 1024-1030.

Carlson, L., Babione, M., Godfrey, P.J., & Fowler, A. (1991) Ecological survey of heathlands in Cape Cod National Seashore, MA, University of Massachusetts, Amherst.

Daubenmire, R. (1968) Ecology of fire in grasslands. *Advanced Ecological Restoration*, **5**, 209-266.

Dhillion, S. & Anderson, R.C. (1993) Growth dynamics and associated mycorrhizal fungi of little bluestem grass (*Schizachyrium scoparium* (Michx.) Nash) on burned and unburned sand prairies. *New Phytologist*, **123**, 77-91.

Dunwiddie, P.W. (unpublished manuscript). Priorities and Progress in Management of Sandplain Grasslands and Coastal Heathlands in Massachusetts.

Dunwiddie, P.W. (1989) Forest and Heath: the shaping of the vegetation of Nantucket Island. *Journal of Forest History*, **33**, 126-133.

Dunwiddie, P.W. 1990. Postglacial vegetation history of coastal islands in southeastern New England. *National Geographic Research* 6:178-195.

Dunwiddie, P.W. (1994) *Martha's Vineyard landscapes: the nature of change* The Vineyard Conservation Society, Edgartown, MA.

Dunwiddie, P.W. (1998) Ecological management of sandplain grasslands and coastal heathlands in southeastern Massachusetts. In Tall Timbers Fire Ecology Conference, Vol. 20, pp. 83-93.

Dunwiddie, P.W. & Caljouw, C. (1990). Prescribed burning and mowing of coastal heathlands and grasslands in Massachusetts. In *Ecosystem Management: rare species and significant habitats* (eds R.S. Mitchell, C.J. Sheviak & D.J. Leoplod), Vol. Bull 471, pp. 271-275. New York State Museum, Albany, NY.

Godfrey, P. J., and P. Alpert. 1985. Racing to save the coastal heaths. The Nature Conservancy News 7/8 1985:11-13.

Gotellli, N.J. & Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in measurement and comparison of species richness. *Ecological Letters.* **4**:379–391.

Hesling, J.L. & Grese, R.E. 2010. Assessing Plant Community Changes over Sixteen years of Restoration in a Remnant Michigan Tallgrass Prarie. *American Midland Naturalist*. **164**: 322-336.

Hurlbert, L. (1988) Causes of fire effects in tallgrass prairie. *Ecology*, **69**, 46-58.

IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

Keetch, J.J. & Byram, G.M. (1968) A drought index for forest fire control (ed U. Southeast Forest Experimental Station), Vol. SE-38, pp. 32. Forest Service Research Paper.

Levitt, J. 1980. Responses of plants to environmental stresses. Volume 1: Chilling, freezing, and high temperature stresses. Academic Press: New York.

[MA NHESP].2007. Natural Heritage & Endangered Species Program Natural Communities Fact Sheets: Scrub Oak Shrublands, Sandplain Grassland, Sandplain Heathlands. < http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/natural-communities/natural-community-fact-sheets.html> . Accessed March 2014.

Mellow, M. (2004). Inventory of Lepidoptera on Nantucket with particular attendion to critical habitat for state-listed species, Rep. No. 2004-1. Lloyd Center.

Motzkin, G., and D.R. Foster. 2002. Grasslands, heathlands and shrublands in coastal New England: historical interpretations and approaches to conservation. Journal of Biogeography 29:1-22

Natural Heritage, E.S.P. (2001) *BioMap: Guiding land conservation for biodiversity in Massachusetts* Massachusetts Division of Fisheries & Wildlife.

Niering, W.A. & Dreyer, G.D. (1989) Effects of prescribed burning on *Andropogon scoparius* i postagricultural grasslands in Connecticut. *American Midland Naturalist*, **122**, 88-102.

[NSE] NatureServe Explorer Home Page. 2009. Available online < http://www.natureserve.org/explorer> Accessed June 2014.

Ojima, D.S., Schimel, D.S., Parton, W.J., & C.E., O. (1994) Long- and short-term effects of fire on nitorgen cycling in tallgrass prairie. *Biogeochemistry*, **24**, 67-84.

Old, S.M. (1969) Microclimate, fire and plant production in an Illinois prairie. *Ecological Monographs*, **39**, 355-384.

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Raleight, L., Capece, J., & Berry, A. (2003) *Sand Barrens habitat management: a toolbox for managers* The Trustees of Reservations, Vineyard Haven, MA.

Richter, D.D., Ralston, C.W., & Harms, W.R. (1982) Prescribed fire: effects on water quality and forest nutrient cycling. *Science*, **215**, 661-663.

Sorrie, B. A., and P.W. Dunwiddie. 1996. The Vascular and Non-Vascular Flora of Nantucket, Tuckernuck, and Muskeget Islands. Massachusetts Audubon Society, MA Natural Heritage and Endangered Species Program, Nantucket Maria Mitchell Association, The Nature Conservancy. Nantucket, MA, USA.

Steel, J. (1999) *Losing ground: an analysis of recent rates and patterns of development and their effects on open space in Massachusetts*, 2nd edn. Massachusetts Audubon Society, Lincoln, MA.

Swain, P.C., and J. B. Kearsley. 2001. Classification of the Natural Communities of Massachusetts. Natural Heritage & Endangered Species Program, MA Division of Fisheries and Wildlife. Westborough, MA.

Tiffney, W.N. and D.E. Eveleigh. 1985. Nantucket's endangered maritime heaths. Pp.1093-1109 *in* Magoon, O.T, H. Converse, D. Miner, D. Clark, and L. T. Tobin (eds.) Coastal Zone '85. Proceedings of the Fourth Symposium on Coastal and Ocean Management, Baltimore, MD, July 30-August 2, 1985.

Vickery, P.D. (2002) Effects of the size of prescribed fire on insect predation of northern blazing star, a rare grassland perennial grassland, prescribed fire, Liatris scariosa, seed predation, seed viability, habitat management, rare species. *Conservation Biology*, **16**, 413-421.

Wally, A.L., Menges, E.S., & Weekley, C.W. (2006) Comparison of three devices for estimating fire temperature in ecological studies. *Applied Vegetation Science*, **9**, 97-108.

Wright, H.A. & Bailey, A.W. 1982. Fire Ecology. Wiley, New York, New York.

Figures and Tables

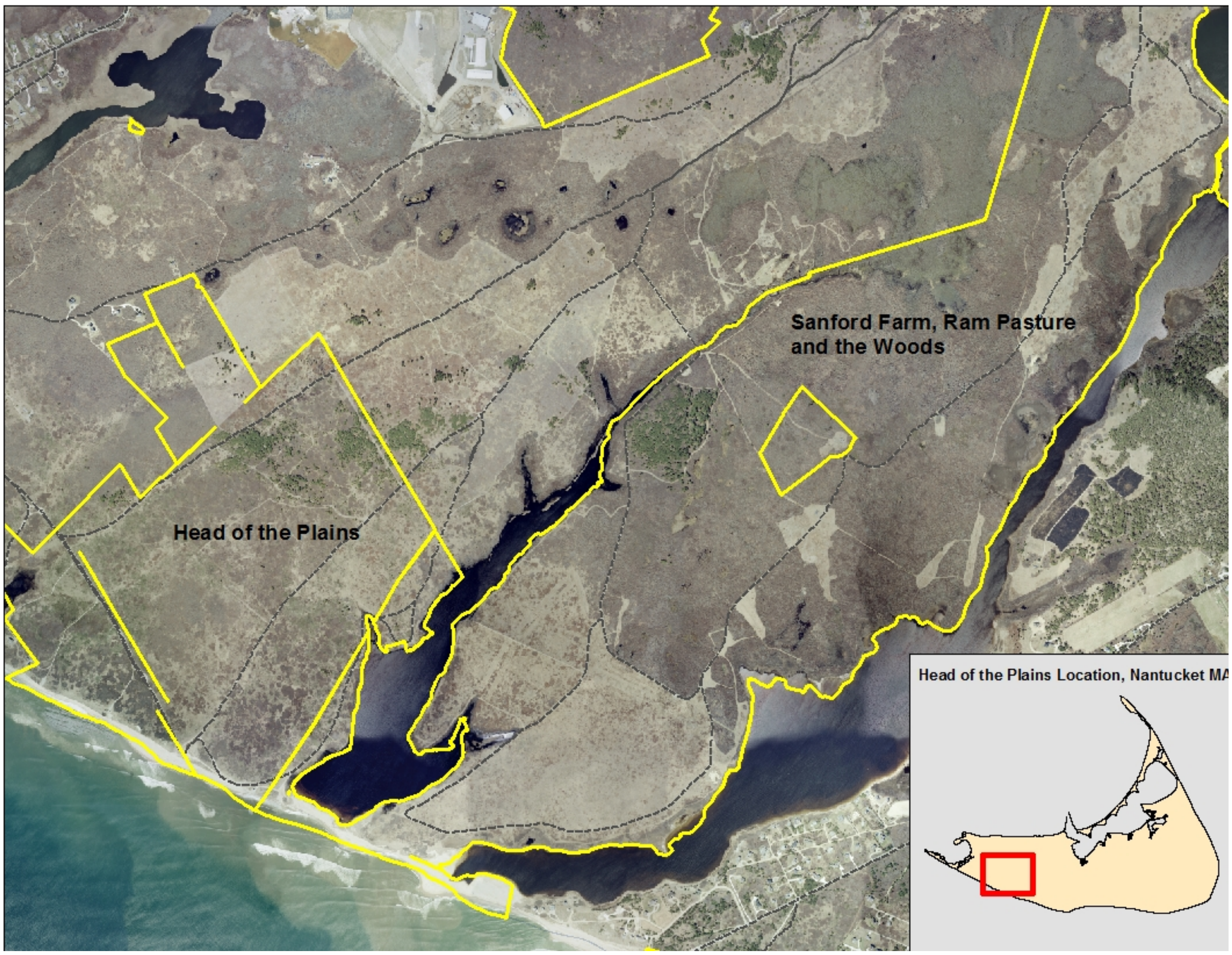

Figure 1: Head of the Plains and Sanford Farm, Ram Pasture and the Woods conservation areas on Nantucket, MA.

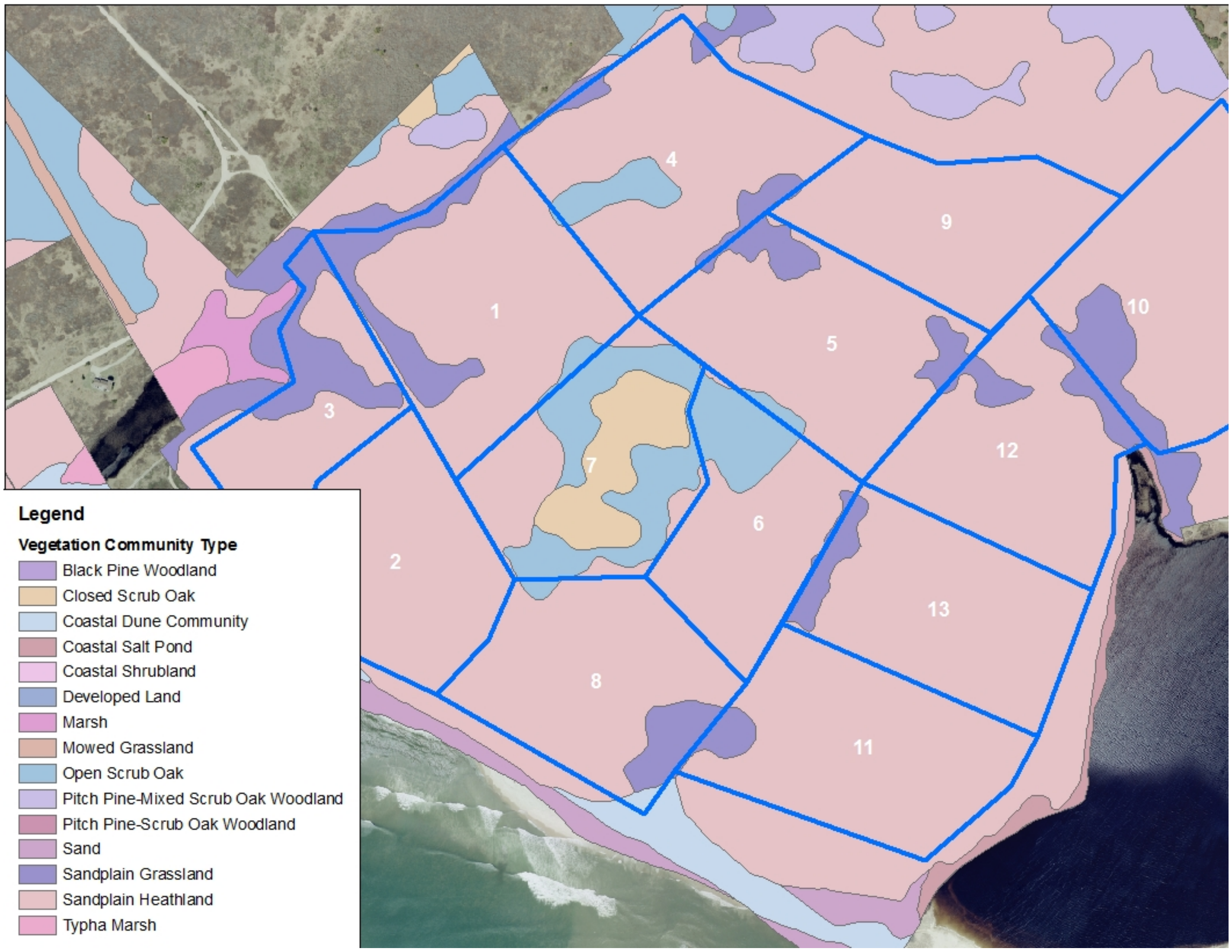

Figure 2: Vegetation Communities delineated at the Head of the Plains, Nantucket MA.

Figure 3: Management Units and vegetation sampling plots at the Head of the Plains, Nantucket MA.

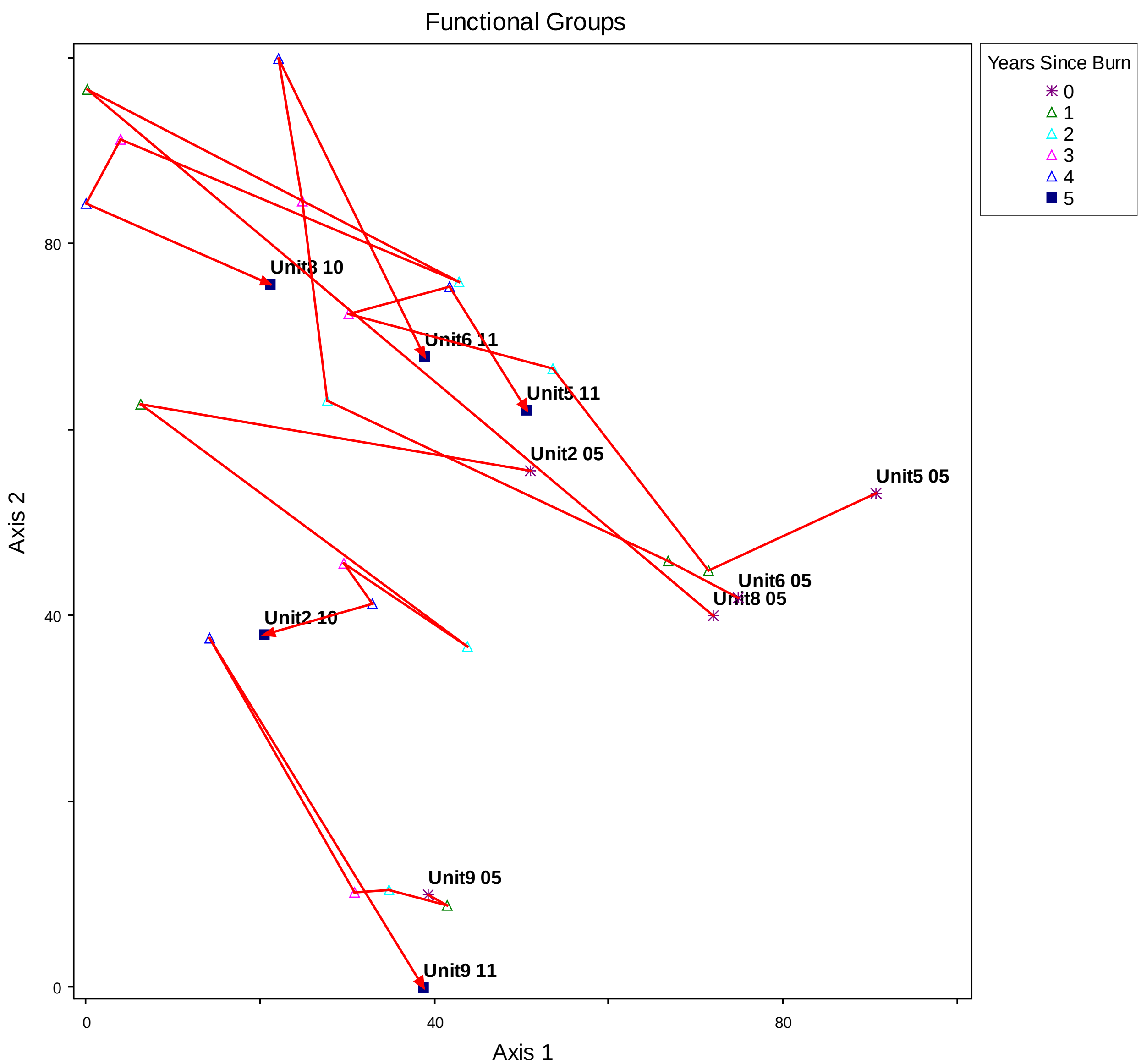

Figure 4: Three-dimensional NMS ordination of vegetation composition within each management Unit; axis 1 (positively correlated with Sandplain Heathland vegetation) and axis 2 (positively correlated with Sandplain Grassland vegetation) are shown. Axes 1, 2, and 3 accounted for a total of 85% of the observed variation. The distance between points is proportional to the dissimilarity in species composition, representing the relative changes in functional group composition between samples. Individual points are labeled with the Unit name and the Sampling Year. (Unit9 05 = Unit 9 sampled in 2005).

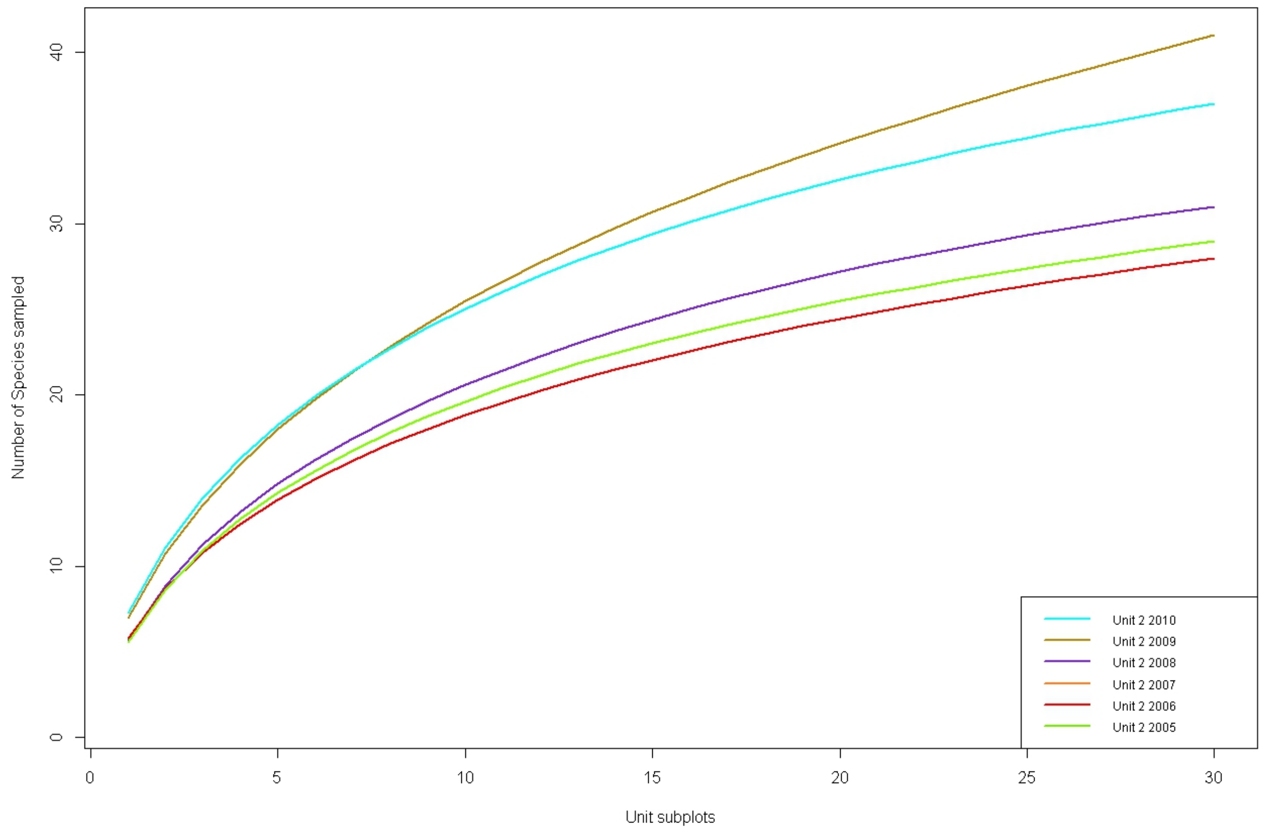

Figure 5: Species rarefaction curves for Unit 2 over time. 2005 represents pre-burn sampling, 2006-2010 represent post-burn sampling. In all Figures 5-9, line colors corrolate with pre-burn (green) and years post-burn: 1yr (red), 2yrs (orange), 3yrs (purple), 4yrs (brown) and 5yrs (teal). The line for Unit2 2007 is located exactly under the Unit 2 2008 line.

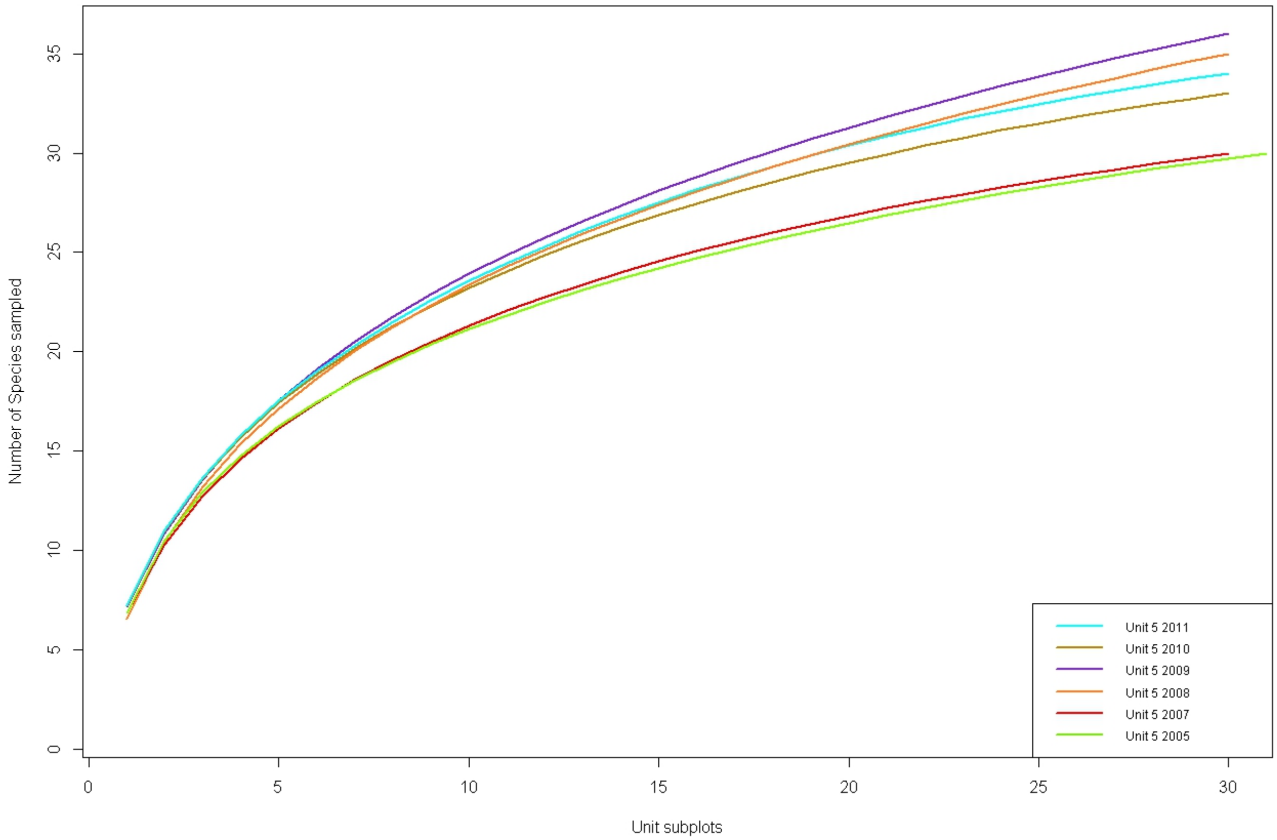

Figure 6: Species rarefaction curves for Unit 5 over time. 2005 represents pre-burn sampling, 2007-2011 represent post-burn sampling. . In all Figures 5-9, line colors corrolate with pre-burn (green) and years post-burn: 1yr (red), 2yrs (orange), 3yrs (purple), 4yrs (brown) and 5yrs (teal).

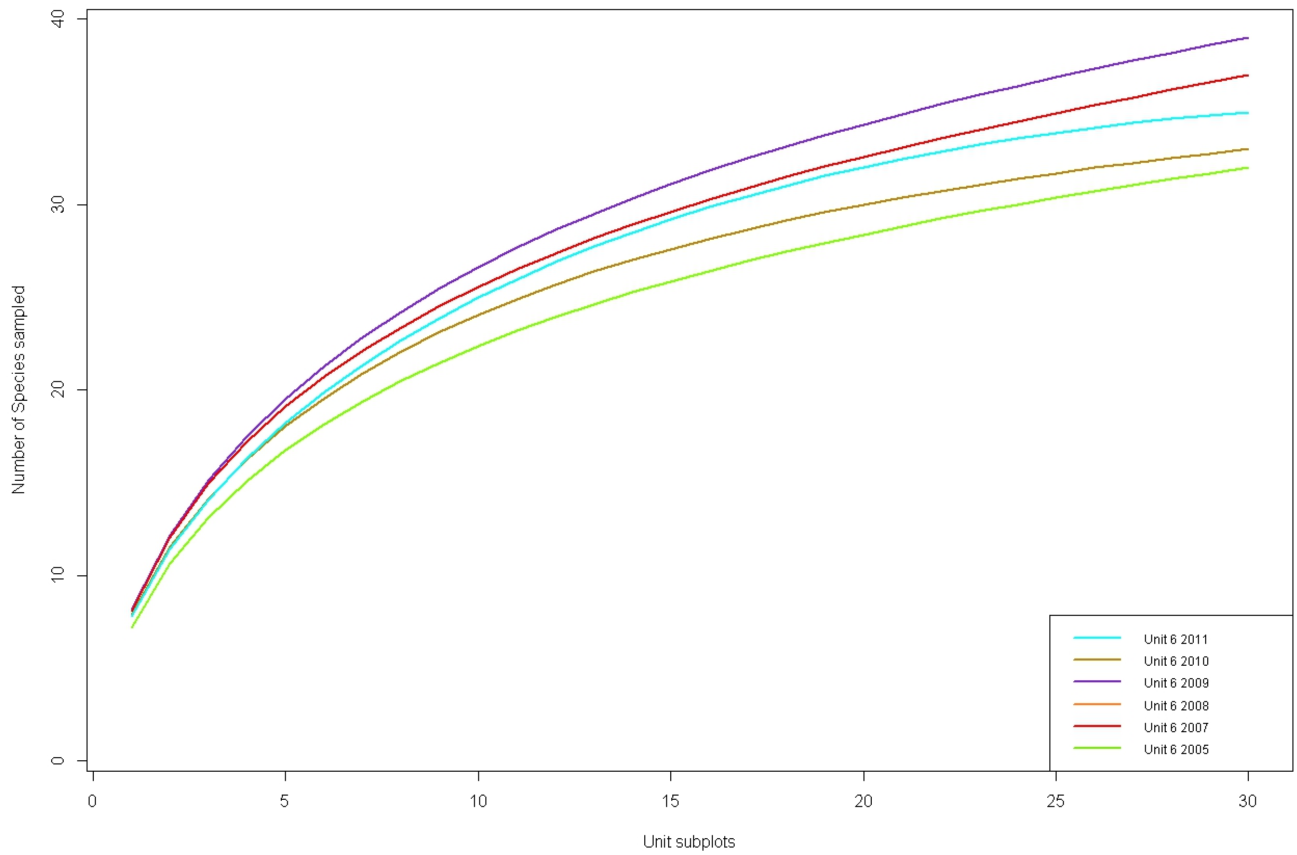

Figure 7: Species rarefaction curves for Unit 6 over time. 2005 represents pre-burn sampling, 2007-2011 represent post-burn sampling. . In all Figures 5-9, line colors corrolate with pre-burn (green) and years post-burn: 1yr (red), 2yrs (orange), 3yrs (purple), 4yrs (brown) and 5yrs (teal). The line for Unit 6 2008 is located exactly under the Unit 6 2007 line.

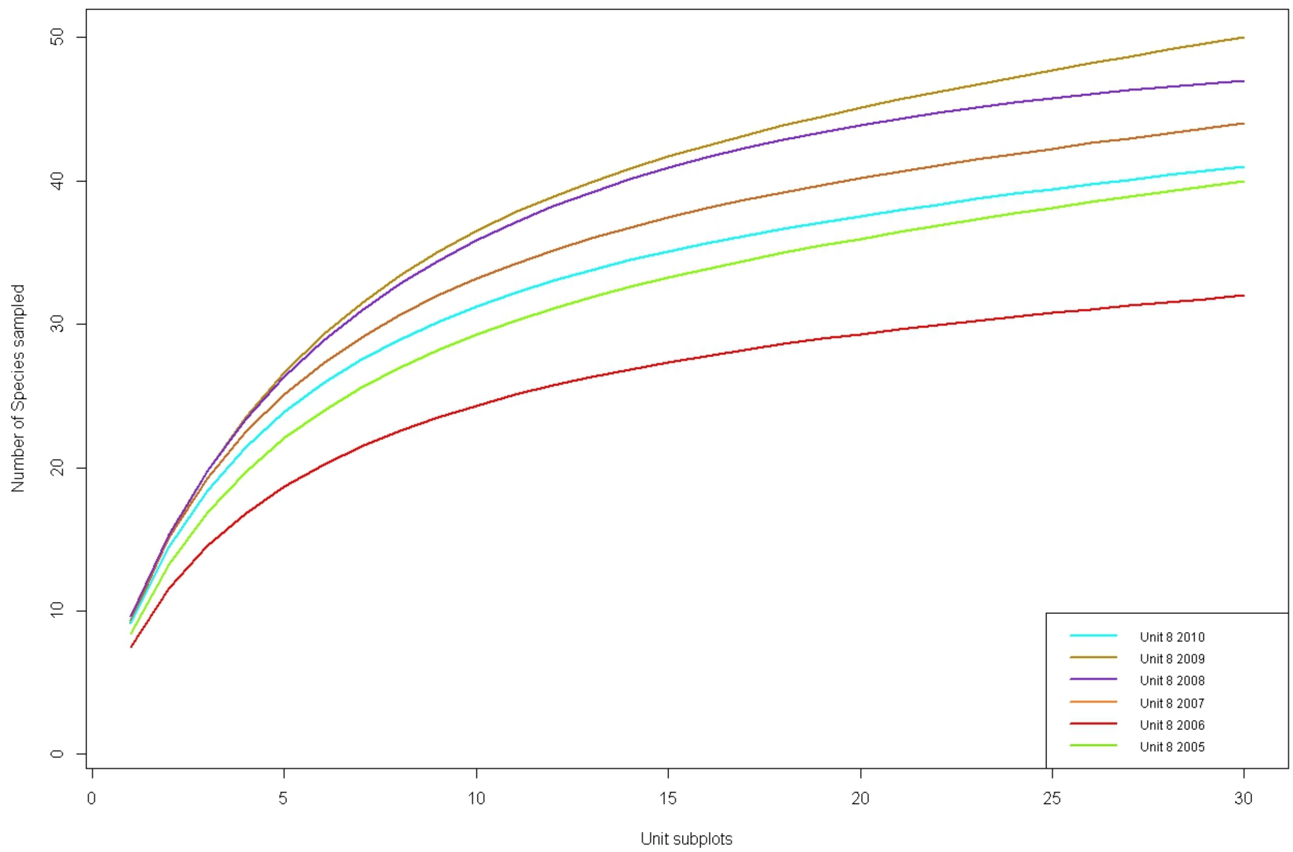

Figure 8: Species rarefaction curves for Unit 8 over time. 2005 represents pre-burn sampling, 2006-2010 represent post-burn sampling. In all Figures 5-9, line colors corrolate with pre-burn (green) and years post-burn: 1yr (red), 2yrs (orange), 3yrs (purple), 4yrs (brown) and 5yrs (teal).

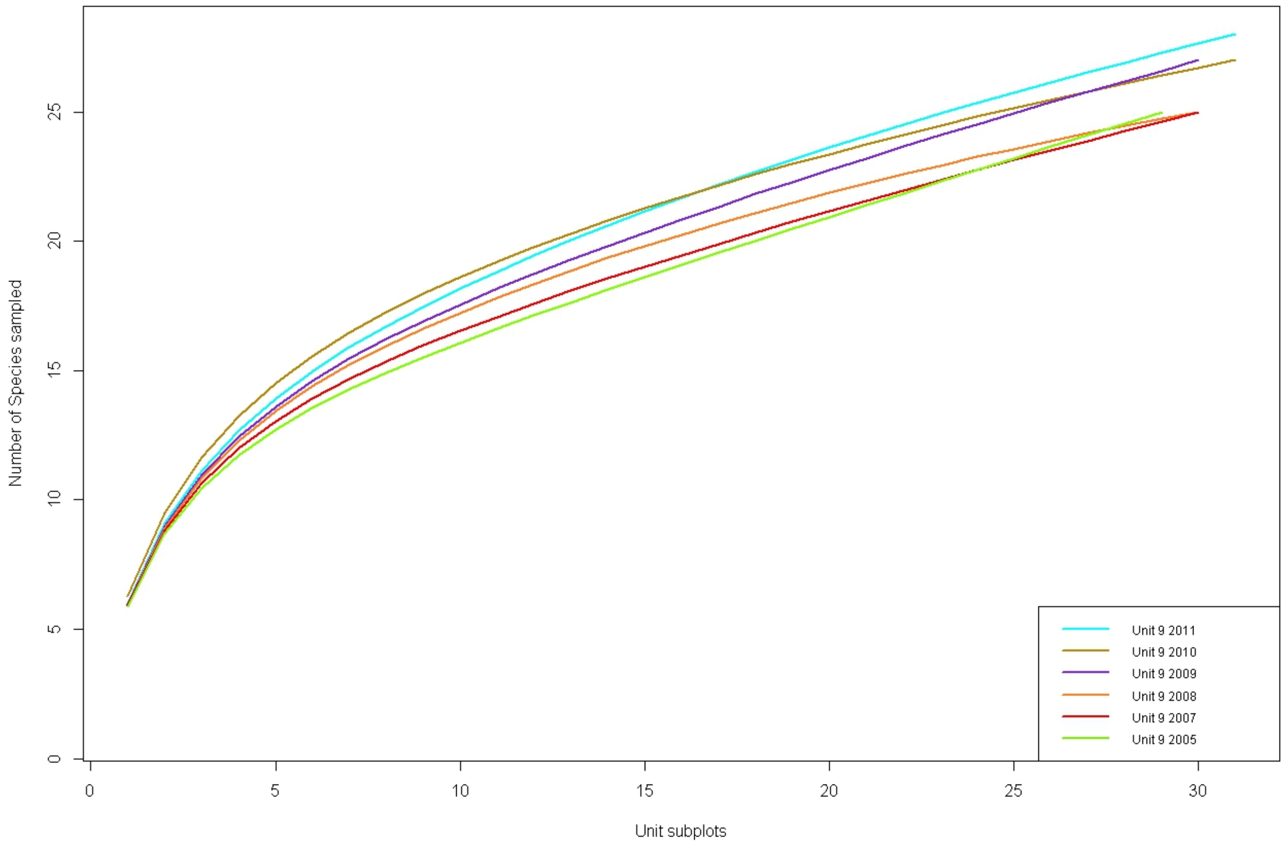

Figure 9: Species rarefaction curves for Unit 9 over time. 2005 represents pre-burn sampling, 2007-2011 represent post-burn sampling. . In all Figures 5-9, line colors corrolate with pre-burn (green) and years post-burn: 1yr (red), 2yrs (orange), 3yrs (purple), 4yrs (brown) and 5yrs (teal).

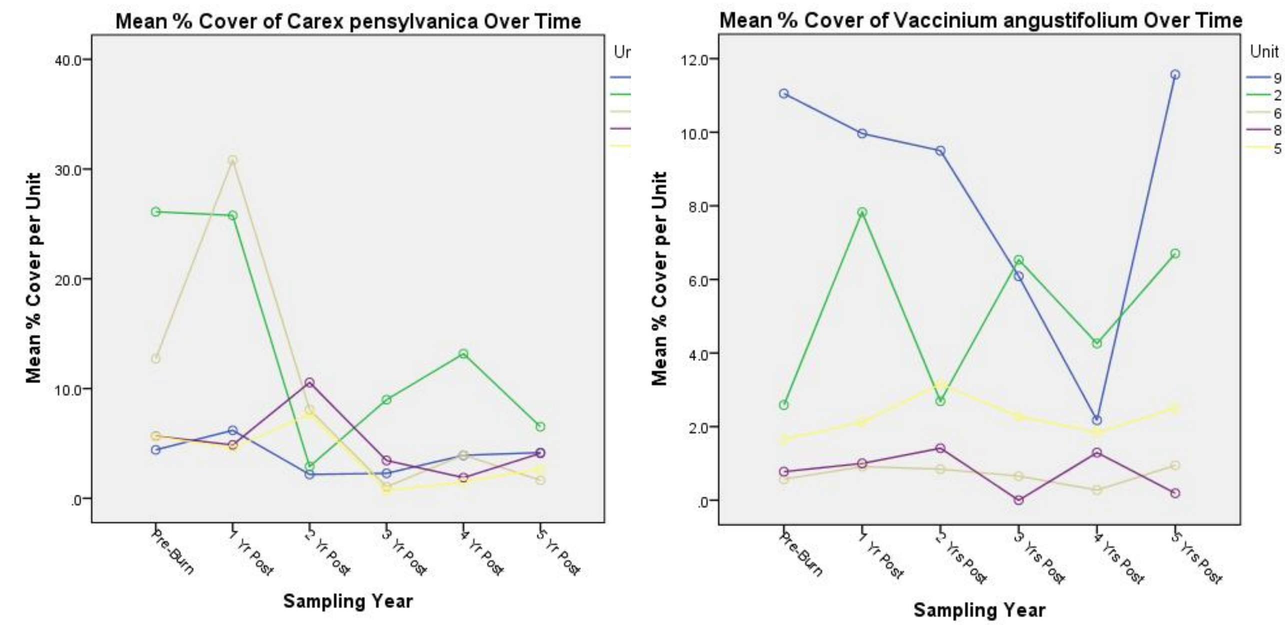

Figure 10: Mean percent cover of *Carex pensylvanica* and *Vaccinium angustifolium* in Units 9, 2, 6, 8, and 5; one year pre-burn treatment and 5 years post-treatment.

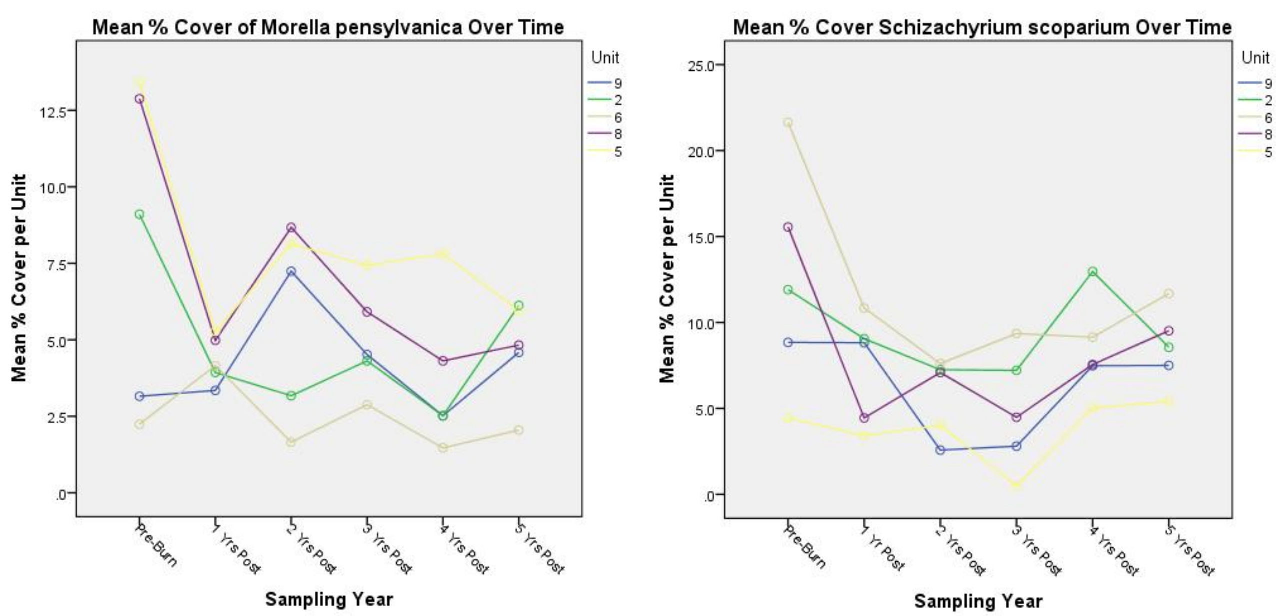

Figure 11: Mean percent cover of *Morella pensylvanica* and *Schizachyrium scoparium* combined in Units 9, 2, 6, 8, and 5; one year pre-burn treatment and 5 years post-treatment.

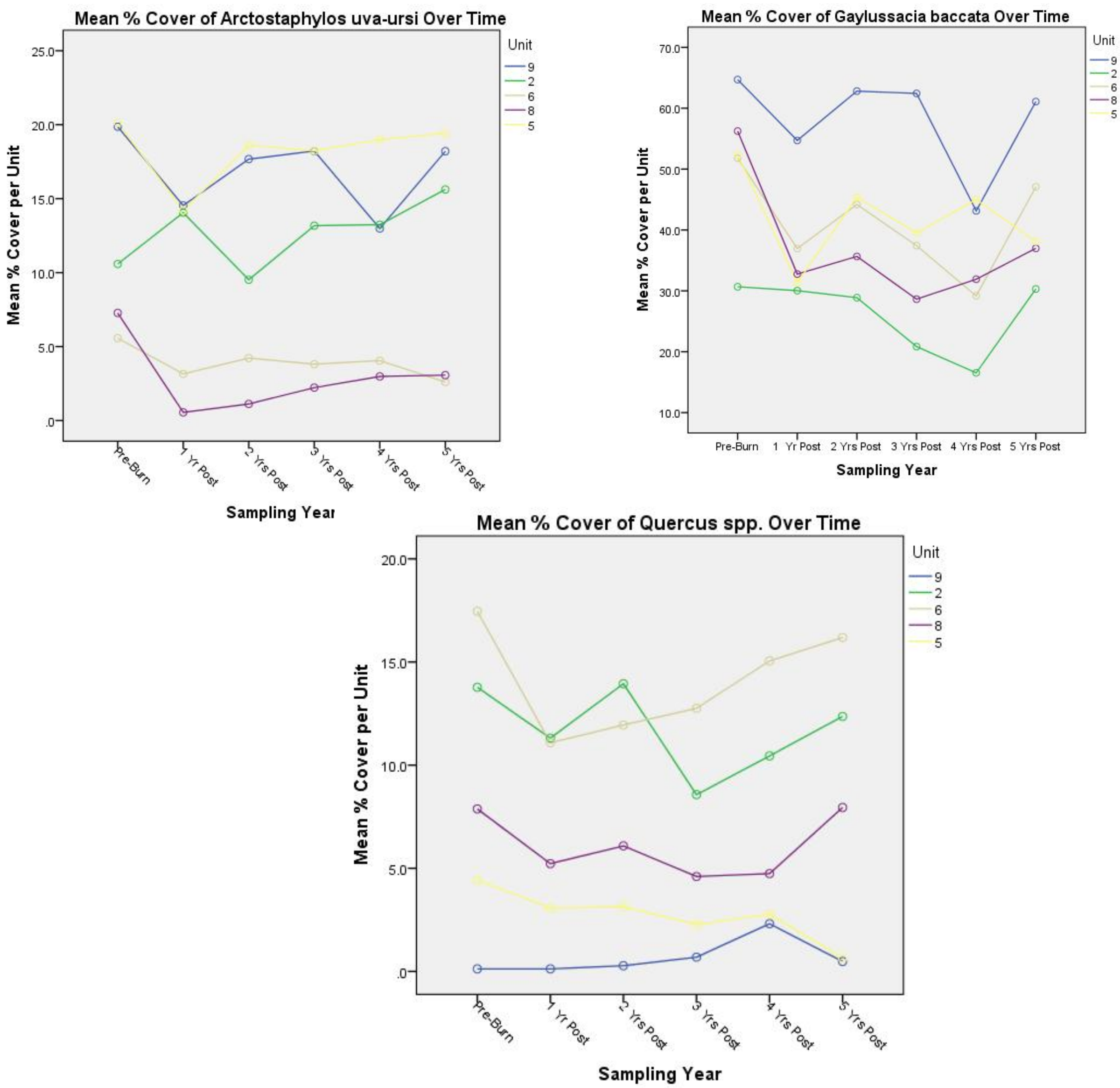

Figure 12: Mean percent cover of *Arctostaphylos uva-ursi*, *Gaylussacia baccata*, and *Quercus ilicifolia* and *Q. prinoides* combined in Units 9, 2, 6, 8, and 5; one year pre-burn treatment and 5 years post-treatment.

Table 1: Time schedule of burns and vegetation sampling at each Unit over time. Pre-S stands for pre-burn vegetation sampling and Post-S for post-burn sampling. Highlighting indicates Units analyzed for this study which had both pre-treatment and 5 years of post-treatment sampling.

Year	Unit 1	**Unit 2**	Unit 3	Unit 4	**Unit 5**	**Unit 6**	**Unit 8**	**Unit 9**	Unit 11
2005		Pre-S **Fall Burn**			Pre-S	Pre-S	Pre-S **Summer Burn**	Pre-S	
2006	Pre-S	Post-S	Pre-S	Pre-S	**Summer Burn**	**Spring Burn**	Post-S	**Fall Burn**	
2007	Pre-S	Post-S	Pre-S	Pre-S	Post-S	Post-S	Post-S	Post-S	
2008		Post-S			Post-S	Post-S	Post-S	Post-S	
2009	Pre-S	Post-S	Pre-S	Pre-S	Post-S	Post-S	Post-S	Post-S	Pre-S
2010	**Spring Burn** Post-S	Post-S			Post-S	Post-S	Post-S	Post-S	
2011	Post-S				Post-S	Post-S	Post-S	Post-S	

Table 2: Environmental, fire and site conditions related to prescribed fires conducted within each Unit. Keetch-Byram Drought Index (KBDI), Mean60 and Mean150 are defined in the Methods. Severity indices (High, Moderate, Low, Scorch, Unburned) indicate the percentage of vegetation plots impacted by varied levels of fire intensity.

	Unit 2	**Unit 5**	**Unit 6**	**Unit 8**	**Unit 9**
Burn Year	2005	2006	2006	2005	2006
Burn Season	Fall	Summer	Spring	Summer	Fall
Burn KBDI	3	92	0	268	46
Mean 60	104 min	75 min	117 min	145 min	66 min
Mean 150	50 min	24 min	58 min	52 min	25 min
High Severity	0%	0%	7%	20%	0%
Moderate Severity	73%	20%	47%	47%	30%
Low Severity	10%	47%	43%	23%	30%
Scorch	0%	10%	3%	10%	0%
Unburned	17%	23%	0%	0%	40%
% Plots Burned during Fire	86.6%	76.6%	100%	100%	80%

Table 3: Pearson and Kendall correlations with nMDS ordination. Axes are related to functional group categories over all sampling Units. Bold indicates higher r^2 values correlating with each axis.

	Axis 1			Axis 2			Axis 3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Functional Group									
TotCover	0.394	0.155	0.232	0.524	0.275	0.335	-0.372	0.138	-0.203
Canopy	0.234	0.055	0.062	0.452	0.204	0.252	-0.523	0.273	-0.21
Woody	0.606	0.368	0.42	0.018	0	0.069	-0.632	0.399	-0.397
Woody1	0.325	0.106	0.216	-0.315	0.099	-0.129	-0.079	0.006	-0.023
Woody2	0.416	0.173	0.375	0.439	0.193	0.241	-0.705	**0.497**	-0.471
DeadWoody	0.33	0.109	0.21	0.404	0.163	0.237	-0.308	0.095	-0.002
Graminoid	-0.101	0.01	-0.113	0.735	**0.54**	0.444	0.271	0.074	0.09
Forb	-0.47	0.221	-0.304	0.046	0.002	0.005	0.185	0.034	0.152
Grassland	0.28	0.078	0.209	0.715	**0.512**	0.517	0.597	0.356	0.402
Heathland	0.943	**0.89**	0.787	0.595	0.354	0.437	-0.144	0.021	-0.051
Shrubland	-0.483	0.234	-0.301	0.59	0.348	0.356	-0.058	0.003	-0.053

Table 4: Pearson and Kendall correlations with nMDS ordination Axes related to measured environmental variables over all sampling Units. Bold indicates higher, r^2 values correlating with each axis.

	Axis 1			Axis 2			Axis 3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Environmental Variables									
GRTemp	0.139	0.019	0.179	0.012	0	0.149	-0.099	0.01	-0.125
GRPrecip	-0.394	0.155	-0.292	-0.776	**0.603**	-0.641	0.338	0.114	0.189
AvTemp	0.046	0.002	-0.007	-0.088	0.008	-0.061	0.186	0.034	0.179
AVPrecip	-0.302	0.091	-0.179	-0.368	0.135	-0.243	0.376	0.141	0.233
BurnIndex	-0.591	**0.35**	-0.526	-0.285	0.081	-0.177	-0.156	0.024	-0.071
BurnRank	-0.62	**0.384**	-0.526	-0.251	0.063	-0.177	-0.112	0.012	-0.071
KBDI	-0.405	0.164	-0.142	-0.196	0.038	-0.005	0.114	0.013	0.182
Distance	0.557	**0.31**	0.394	0.263	0.069	0.217	-0.018	0	-0.01

Table 5: *F*- statistics, degrees of freedom and *p*-values for repeated measures analysis of variance over time of individual indicator species within each management unit at the Head of the Plains, Nantucket Island, MA.

	Species	*F*-stat	df	*p*-value
	Schizachyrium scoparium	2.362	3.021	0.077
	Carex pensylvanica	4.306	2.392	**0.013**
Unit	*Gaylussacia baccata*	5.741	4	**0.001**
	Vaccinium angustifolium	3.282	1.961	**0.046**
	Arctostaphylos uva-ursi	2.956	2.536	**0.046**
	Morella pensylvanica	1.131	2.472	0.337
	Quercus spp.	3.615	2.759	**0.02**
	Schizachyrium scoparium	11.353	3.446	**0.001**
	Carex pensylvanica	23.282	3.066	**0.001**
Sample Year	*Gaylussacia baccata*	26.15	5	**0.001**
	Vaccinium angustifolium	2.147	3.373	0.092
	Arctostaphylos uva-ursi	1.62	3.391	0.184
	Morella pensylvanica	7.182	3.502	**0.001**
	Quercus spp.	2.804	3.235	**0.04**

Appendix A: Study Site and Research Project Photographs

Head of the Plains Sandplain grassland and heathland communities (photo credit: Kelly A Omand 8/26/2014)


Head of the Plains Sandplain grasslands and heathlands

Paired plots to estimate burn severity in sampling plots within each burned unit.

Unit 2, November 2005 pre-burn plot photo

Unit 2, November 2005 immediately post-burn photo

Head of the Plains Fall Burn


Head of the Plains spring burn